PROCEEDINGS OF SCIENCE

A precision measurement of fiducial and differential cross-sections of WW production with the ATLAS detector

José Antonio Fernández Pretel[a,*] **on behalf of the ATLAS Collaboration**

[a] *Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany*

E-mail: jose.pretel@cern.ch

Measuring production of W-boson pairs at particle colliders provides an important test of the predictions of Standard Model (SM) of particle physics in both perturbative quantum chromodynamics and electroweak domains. In this measurement, fiducial and differential cross-sections are obtained using data recorded with the ATLAS detector between 2015 and 2018 in proton-proton collisions at center-of-mass energies of 13 TeV at the Large Hadron Collider, corresponding to an integrated luminosity of 140 fb^{-1}. The number of events due to top-quark pair production, the largest background, is reduced by rejecting events containing jets with b-hadron decays. Background contributions from top-quark and non-prompt leptons are estimated using data-driven techniques. In contrast to most of the previous measurements that enhance the W^+W^- signal purity by vetoing hadronic jets in the final state, this is the first measurement of W^+W^- cross-sections using a fully jet-inclusive selection. The fiducial W^+W^- cross-section is determined in a maximum-likelihood fit with an uncertainty of 3.1%, providing the most precise cross-sections of W^+W^- production achieved in hadron-hadron collisions to date. The measurement is extrapolated to the full phase space, resulting in a total W^+W^- production cross-section of 124 ± 4 pb. Differential cross-sections are measured as a function of twelve observables describing the kinematics of the W^+W^- system. State-of-the-art theory predictions of the SM are in excellent agreement with the data.

EPS-HEP Conference 2023
21-25 August 2023
University of Hamburg, Hamburg, Germany

[*] Speaker

PoS(EPS-HEP2023)318

1. Introduction

Experimental investigations of diboson processes in proton-proton (pp) collisions at the center-of-mass energies accessible at the Large Hadron Collider (LHC) [1] offer insights into gauge vector boson self-couplings predicted by the electroweak sector of the Standard Model (SM) and the proton structure. The $SU(2)\otimes U(1)$ gauge structure of the electroweak theory governs the couplings of three vector bosons in the SM. Differential production cross-section measurements of W^+W^- production serve as vital tests for perturbative corrections in quantum chromodynamics (QCD) and electroweak (EW) theories, probing contributions from anomalous couplings that might enhance this production. Accurate measurements of W^+W^- production are also important inputs in background estimates for other measurements of SM processes such as Higgs boson production as well as searches for physics beyond the SM (BSM).

This manuscript presents the latest W^+W^- production cross-section measurement at a center-of-mass energy of $\sqrt{s}$ = 13 TeV using data recorded with the ATLAS detector [2] between 2015 and 2018 (LHC's Run 2), corresponding to an integrated luminosity of 140 fb^{-1} [3].

2. Measurements of W^+W^- production cross sections

The best signal-to-background ratio in W^+W^- production is achieved using fully leptonic decays. With such a signature, large irreducible backgrounds arise after the production of top-quarks, dominated by $t\bar{t}$, and Drell-Yan Z+jets. The former were traditionally suppressed by rejecting events with jets in the final state, which follows in increased theoretical and experimental uncertainties. For the first time, ATLAS reports fiducial integrated and differential cross-section measurements of the W^+W^- production in a fully jet-inclusive phase space using the full Run 2 dataset corresponding to 140 fb^{-1}, allowed by accurate data-driven estimation of the $t\bar{t}$ and lepton misidentification backgrounds [3]. Using fully leptonic decays into one electron and one muon of opposite electric-charge, Drell-Yan contributions are suppressed by requiring a dilepton invariant mass greater than 85 GeV. Top-quark contributions, comprising 48% of the overall SM prediction and 80% of the total background within the fiducial region, are mitigated by rejecting events featuring jets involving b-hadron decays (b-jets).

Contributions from $t\bar{t}$ events are estimated by an in-situ determination of both the $t\bar{t}$ effective production cross-section and the b-jet reconstruction efficiency bin by bin, using two regions with exactly 1 and 2 b-jets. Input from Monte Carlo (MC) simulations is required to infer the correlations between reconstructing the first and the second b-jet in the event [4]. Single-top contributions, dominated by Wt production, are estimated using MC simulation [4]. Background contributions due to lepton misidentification are estimated after extrapolation from a control region where one of the leptons in the final state fulfills a selection criteria designed to select mostly misidentified leptons. The extrapolation factors are determined in a region dominated by multijet production, where a lepton candidate recoiling from a jet is selected. Events arising from Drell-Yan Z-boson and diboson (VZ and $V\gamma$, with $V = W, Z$) production are estimated using MC simulation [5]. The modelling of each background source is validated in dedicated regions, where the data are well described within uncertainties. The top-enriched region and the same-sign validation regions are presented in Figures 1a and 1b, respectively. The data and the SM prediction in the signal region are shown in bins of the jet multiplicity in Figure 1c.

PoS(EPS-HEP2023)318

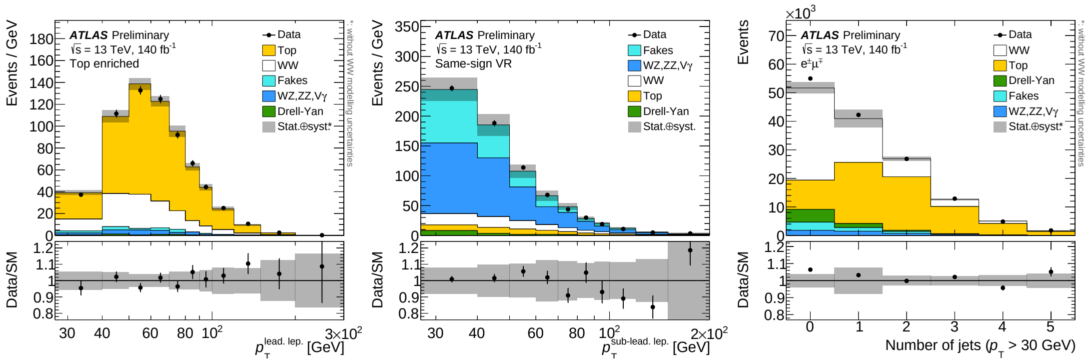

Figure 1: Pre-fit distributions at reconstructed level of (a) the leading lepton p_T in the top-enriched region, (b) the sub-leading lepton p_T in the same-sign validation region and (c) the jet multiplicity in the jet-inclusive signal region enhancing W^+W^- production. Contributions from top-quark production and lepton misidentification are estimated using data-driven techniques. Uncertainties show sum in quadrature of statistical and systematic sources, excluding W^+W^- modelling uncertainties. Source: [3].

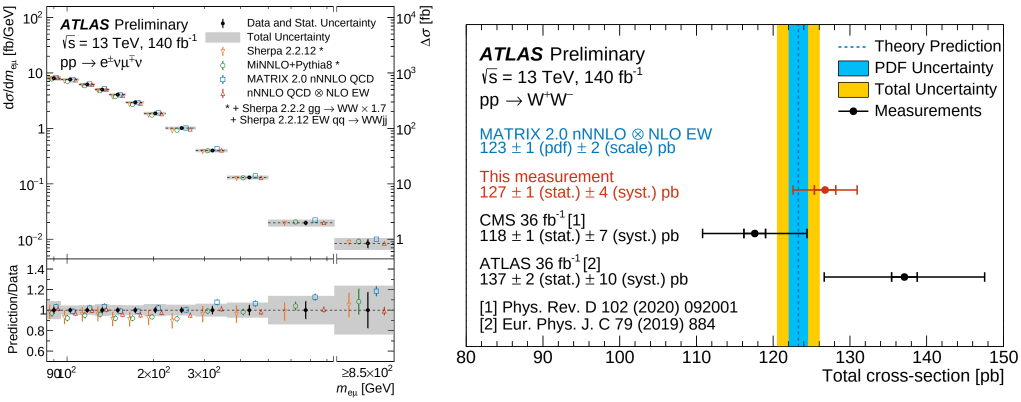

Figure 2: Measurements of (a) the fiducial differential W^+W^- production cross-section as a function of the dilepton invariant mass, $m_{e\mu}$, compared to state-of-the-art theory predictions derived in MiNNLO, MATRIX 2.0.1 [8] at both nNNLO in QCD and nNNLO QCD⊗NLO EW and Sherpa 2.2.12 [5], and (b) the total W^+W^- production cross-section, compared to the state-of-the-art SM prediction from MATRIX 2.0.1 as well as previous ATLAS [10] and CMS [11] measurements using the partial Run 2 dataset recorded between 2015 and 2016. Source: [3].

Unfolded distributions across twelve differential observables related to the kinematics of leptons, jets and E_T^{miss} in the event are reported in a fiducial region close to the signal region at detector level. State-of-the-art theory, predictions derived with Sherpa 2.2.12 [5] at next-to-leading order (NLO) in QCD, MiNNLO+Pythia8 [6, 7] at next-to-next-to-leading order (NNLO) accuracy in QCD, as well as fixed-order predictions from MATRIX 2.0.1 [8] at both NNLO in QCD and NNLO QCD⊗NLO EW, including also $gg \to W^+W^-$ at QCD-NLO and $\gamma\gamma \to W^+W^-$ production (nNNLO), are in excellent agreement with the data. The differential cross-section as a function of the dilepton invariant mass $m_{e\mu}$ is shown in Figure 2a. The integrated fiducial cross-section is obtained by multiplying the unconditional maximum-likelihood estimate of signal strength modifier μ times the particle level fiducial cross-section prediction of the signal model, accounting for all theoretical and experimental systematic uncertainties as Gaussian nuisance parameters in the profile likelihood fit. A measured fiducial cross-section of $\sigma_{\text{fid}} = 707 \pm 7\,(\text{stat.}) \pm 20\,(\text{syst.})$ fb is obtained, with a total uncertainty of 3.1% dominated by systematic uncertainties of top and lepton misidentification background estimates. The fiducial cross-section measurement is extrapolated to the full phase space based on the acceptance calculated at nNNLO(QCD)⊗NLO(EW) with the MATRIX prediction and a branching ratio of 10.86% [9], in good agreement with previous LHC measurements (Figure 2b) and the state-of-the-art SM prediction.

3. Conclusions

Fiducial differential cross-section measurements of W^+W^- production in proton-proton collisions at a center-of-mass energy of $\sqrt{s}$ = 13 TeV using data recorded with the ATLAS detector between 2015 and 2018 are presented. The measurement is performed in a fully jet-inclusive phase space that allows precise theoretical predictions. Improved data-driven estimations of background contributions from top-quark production and lepton misidentification are also possible in this region, whose systematic uncertainties dominate in a fiducial cross-section determined with a precision of 3.1%. A total W^+W^- cross-section of 127 ± 4 pb is measured after extrapolation to the full phase space. Differential cross-sections are measured as a function of twelve observables. The most precise W^+W^- production cross-section measurements performed in hadron colliders to date are reported, which are well described by state-of-the-art theoretical predictions of the SM.

References

[1] L. Evans, P. Bryant, *The LHC Machine*, *JINST* 3 S08001, 2008. [doi:10.1088/1748-0221/3/08/S08001].

[2] ATLAS Collaboration, *The ATLAS Experiment at the CERN Large Hadron Collider*, *JINST* 3 S08003, 2008. [doi:10.1088/1748-0221/3/08/S08003].

[3] ATLAS Collaboration, *Measurements of W^+W^- production cross sections in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, ATLAS-CONF-2023-012.

[4] S. Alioli, P. Nason, C. Oleari, E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, *JHEP* 06 (2010) 043 [doi:10.1007/JHEP06(2010)043] [arXiv:1002.2581].

[5] Sherpa Collaboration, *Event Generation with Sherpa 2.2*, *SciPost* Phys. 7 (2019) 3, 034. [doi:10.21468/SciPostPhys.7.3.034] [arXiv:1905.09127].

[6] P. F. Monni, P. Nason, E. Re, M. Wiesemann, G. Zanderighi, *MiNNLO$_{PS}$: a new method to match NNLO QCD to parton showers*, JHEP 05 (2020) 143. [doi:10.1007/JHEP05(2020)143] [arXiv:1908.06987].

[7] D. Lombardi, M. Wiesemann, G. Zanderighi, *W^+W^- production at NNLO+PS with MINNLO$_{PS}$*, *JHEP* 11 (2021) 230. [doi:10.1007/JHEP11(2021)230] [arXiv:2103.12077].

[8] M. Grazzini, S. Kallweit, J. Lindert, S. Pozzorini, M. Wiesemann, *NNLO QCD + NLO EW with Matrix+OpenLoops: precise predictions for vector-boson pair production*, *JHEP* 02 (2020) 087, [doi:10.1007/JHEP02(2020)087] [arXiv:1912.00068].

[9] The Particle Data Group, *Review of Particle Physics*, *PTEP* 2022 (2022) 083C01 [doi:10.1093/ptep/ptac097].

[10] ATLAS Collaboration, *Measurement of fiducial and differential W^+W^- production cross-sections at $\sqrt{s}$ = 13 TeV with the ATLAS detector*, *Eur.Phys.J.C* 79 (2019) 10, 884. [doi:10.1140/epjc/s10052-019-7371-6] [arXiv:1905.04242].

[11] CMS Collaboration, *W^+W^- boson pair production in proton-proton collisions at $\sqrt{s}$ = 13 TeV*, *Phys.Rev.D 102* (2020) 9, 092001. [doi:10.1103/PhysRevD.102.092001] [arXiv:2009.00119].

PoS(EPS-HEP2023)318